# OFFICE MEMO

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| **TO:** Sushil Arora | **DATE:** May 29, 2001 |
| **FROM:** Paul Hutton | **SUBJECT:** ISI In-Delta Storage: CALSIM Water Quality Constraints to Meet Delta Wetlands WQMP **DRAFT** |

The purpose of this memo is to propose CALSIM water quality constraints for evaluating ISI In-Delta Storage Project water supply benefits. Translation of water quality constraints into CALSIM operating rules is discussed in a separate memo to you. For convenience, this memo loosely refers to both the In-Delta Storage Project and the Delta Wetlands Project as the "Project".

Water quality constraints were developed for total organic carbon (TOC), disinfection by-product (DBP) formation and chloride in accordance with Attachments 2 and 3 of the Delta Wetlands Water Quality Management Plan (WQMP) and water quality objectives outlined in the SWRCB's Decision 1643 for the Project. By employing several assumptions, many of which are specified in the WQMP, the constraints were defined in terms of ambient water temperature and three DSM2 simulation constituents -- dissolved organic carbon (DOC), ultraviolet absorbance at 254 nm (UVA), and electrical conductivity (EC). DOC is employed as a surrogate for TOC; EC is employed as a surrogate for bromide and chloride.

CALSIM requires information on how to operate the Project while meeting the water quality constraints proposed in this memo. The information must guide model decisions related to magnitude and timing of Project storage diversions and releases. An artificial neural network (ANN) emulation of DSM2 can directly provide some of the necessary information to CALSIM. CALSIM is currently provided salinity-based (EC) water quality conditions at three Delta locations (Old River at Rock Slough, San Joaquin River at Jersey Point, and Sacramento River at Emmaton) through an ANN flow-salinity routine trained on DSM2 output data. The Delta Modeling Section will develop new ANNs that emulate DSM2 simulations of EC, DOC and UVA at Project diversions and key urban intakes. Regression relationships will be utilized to transform bromide and chloride constraints into EC constraints. Until these ANNs are developed, simple Project operating rules will be developed to approximately meet the water quality constraints.

## General Notes on Water Quality Operational Constraints

### Urban Intakes

The WQMP preamble identifies the following urban intakes as having the potential to be negatively impacted by the Project: Banks Pumping Plant, Tracy Pumping Plant, CCC PP #1, and CCWD's Los Vaqueros and Mallard Slough intakes. Each of these locations will be modeled in DSM2 simulations. However, for the purposes of CALSIM modeling, I recommend that we initially focus on the first four locations. DSM2 post analysis will indicate the need to consider other locations in CALSIM.

### Uncertainty Factor

Attachment 2 of the WQMP establishes an uncertainty factor of ± 5% for determining an exceedance of TOC and DBP formation constraints. While this factor may be useful in evaluating performance in DSM2, I recommend that this factor generally not be invoked for CALSIM operations. The exception to this recommendation is when a DBP constraint is exceeded in a CALSIM base study. Under such a condition, David Forkel interprets the WQMP as allowing the Project to impact DBP concentrations by as much as 5% of the DBP standard. See text below on DBP formation constraints for total trihalomethanes and bromate.

14-Day Averages

In accordance with Attachment 2 of the WQMP, the TOC, DBP and chloride constraints will be enforced as 14-day averages, or the averages for the duration of Project discharge, whichever time period is less.

Temperature & Dissolved Oxygen Constraints

D-1643 sets limits on Project discharge to avoid adverse impacts due to dissolved oxygen depression and water temperature increases. These limits generally relate to the immediate receiving waters (although the DO limit also applies to a reach of the San Joaquin River between Turner Cut and Stockton.) DWR/USBR should investigate whether these limits will have a practical impact on Project yield. However, the Delta Modeling Section does not plan to develop CALSIM constraints for temperature and DO.

**DOC Concentration Constraints**

Paragraph A of Attachment 2 of the WQMP states that the Project cannot cause an increase in TOC of more than 1.0 mg/L and it cannot cause TOC to exceed 4.0 mg/L. The 5% uncertainty factor is not incorporated into the constraint. For purposes of DSM2 and CALSIM modeling, DOC concentration will be assumed equivalent to TOC concentration and the urban intake constraints may be stated mathematically as follows:

| DOC (w/o Project) | DOC (w/ Project) – DOC (w/o Project) |
|---|---|
| 0.0 – 3.0 mg/L | ≤ 1.0 mg/L |
| 3.0 – 4.0 mg/L | linear decrease in constraint value from ≤ 1.0 to ≤ 0.0 mg/L |
| > 4.0 mg/L | ≤ 1.0 mg/L |

**DBP Formation Constraint: Total Trihalomethanes (TTHM)**

Paragraph B.1 of Attachment 2 of the WQMP states that the Project cannot cause or contribute to TTHM concentrations in excess of 64 ug/L, as calculated in the raw water of urban intakes in the Delta. If without project conditions exceed 64 ug/L, the Project is allowed to impact TTHM up to 5% of 64 ug/L, or 3.2 ug/L. This constraint can be defined mathematically as follows:

| TTHM (w/o Project) | TTHM (w/ Project) – TTHM (w/o Project) |
|---|---|
| 0.0 – 60.8 ug/L | linear decrease in constraint value from ≤ 64.0 to ≤ 3.2 ug/L |
| > 60.8 ug/L | ≤ 3.2 ug/L |

where:

$$TTHM = C1 \times DOC^{0.228} \times UVA^{0.534} \times (Br + 1)^{2.01} \times T^{0.48} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

and:

TTHM = total trihalomethane concentration (ug/L)
C1 = 14.5 when DOC < 4.0 mg/L; C1 = 12.5 when DOC ≥ 4.0 mg/L
DOC = raw water dissolved organic carbon (mg/L) as simulated by DSM2
UVA = raw water ultraviolet absorbance at 254nm (1/cm) as simulated by DSM2
Br = raw water bromide concentration (mg/L) as simulated by DSM2
T = raw water temperature (°C)

Attachment 1 tabulates raw water temperatures for use in Eq. (1). The values in Attachment 1 are assumed to represent all years and all urban intakes in the Delta. Derivation of Eq. (1) is provided in Attachment 2. DSM2 salinity simulations will be conducted in terms of EC and ANN results will report salinity results in terms of EC. Attachment 3 develops the above equation in terms of EC instead of Br for the four key urban intakes.

**DBP Formation Constraint: Bromate (BRM)**

Paragraph B.2 of Attachment 2 of the WQMP states that the Project cannot cause or contribute to bromate concentrations in excess of 8 ug/L, as calculated in the raw water of urban intakes in the Delta. If base conditions exceed 8 ug/L, the Project is allowed to impact bromate up to 5% of 8 ug/L, or 0.4 ug/L. This constraint can be defined mathematically as follows:

| Bromate (w/o Project) | Bromate (w/ Project) – Bromate (w/o Project) |
|---|---|
| 0.0 – 7.6 ug/L | linear decrease in constraint value from ≤ 8.0 to ≤ 0.4 ug/L |
| > 7.6 ug/L | ≤ 0.4 ug/L |

where:

$BRM = C2 \times DOC^{0.31} \times Br^{0.73}$ ……………………………………………………………………(2)

and:

BRM = bromate concentration (ug/L)
C2 = 9.6 when DOC < 4.0 mg/L; C = 9.2 when DOC ≥ 4.0 mg/L
DOC = raw water dissolved organic carbon (mg/L) as simulated by DSM2
Br = raw water bromide concentration (mg/L) as simulated by DSM2

Derivation of Eq. (2) is provided in Attachment 4. Attachment 5 develops the above equation in terms of EC instead of Br for the four key urban intakes.

**Chloride Concentration Constraints**

Paragraph C of Attachment 2 of the WQMP states that the Project cannot cause an increase in chloride of more than 10 mg/L and it cannot cause or contribute to any salinity increases at urban intakes exceeding 90% of adopted salinity standards. These constraints may be stated mathematically as follows (see Attachment 6 for a restatement in terms of EC):

| Chloride (w/o Project) | Chloride (w/ Project) – Chloride (w/o Project) |
|---|---|
| At CCC PP#1 when 150 mg/L standard controls: | |
| 0.0 – 135 mg/L | ≤ 10 mg/L |
| > 135 mg/L | ≤ 0 mg/L |
| At urban intakes when CCC PP #1 150 mg/L standard does not control: | |
| 0.0 – 225 mg/L | ≤ 10 mg/L |
| > 225 mg/L | ≤ 0 mg/L |

**Long-Term Constraints**

Paragraph F.3 of the WQMP discusses mitigation of long-term water quality impacts associated with the Project. The paragraph quantifies what is considered to be an unacceptable long-term impact.

However, the period of time considered to be “long-term” is not well defined. The Project is required to mitigate 150% of the net increase in TOC and salt (i.e. TDS, bromide and chloride) loading greater than 5% in the urban diversions due to Project operations. Based upon other wording in Paragraph F, I propose the constraint be written as follows:

[DOC (w/ Project) – DOC (w/o Project)] / DOC (w/o Project) $\leq$ 0.05 ……….……………………(5)
[EC (w/ Project) – EC (w/o Project)] / EC (w/o Project) $\leq$ 0.05 ………….……………………..(6)

where DOC and EC are calculated as flow-weighted 3-year running averages. I propose that these constraints not be dynamically implemented in CALSIM. Rather, these constraints would be checked in a DSM2 post analysis. If a long-term constraint is violated for a particular alternative, an iterative solution could be found by buffering the DOC or salt constraints in CALSIM.

Attachments

Cc: Sanjaya Seneviratne
Tara Smith
Dan Otis

# ATTACHMENT 1
# RAW WATER TEMPERATURES

Temperature data were acquired from David Forkel of Delta Wetlands. These data were utilized in their work with CUWA, and came from CCWD water treatment plant averages as provided by KT Shum. An interpolation scheme was used to generate daily values from the monthly averages tabulated below.

Data from the IEP web site are also tabulated below for comparison only. D-1485 discrete water quality sampling data at Clifton Court Forebay were evaluated for the period 1975-93 to develop the monthly average values. Temperature was measured once or twice each month during the late morning and afternoon hours. Another data set was used to evaluate diurnal variations. This analysis indicted less than 2 degrees variation over a 24-hour period, which is within the standard deviation of the tabulated monthly averages.

| **Month** | **Temperature (°C)** | |
|---|---|---|
| | **CCWD** | **Clifton Court** |
| January | 9 | 9 |
| February | 12 | 11 |
| March | 15 | 14 |
| April | 20 | 16 |
| May | 23 | 19 |
| June | 24 | 22 |
| July | 24 | 24 |
| August | 24 | 24 |
| September | 23 | 22 |
| October | 20 | 20 |
| November | 15 | 15 |
| December | 11 | 10 |

# ATTACHMENT 2
# DERIVATION OF THE TTHM CONSTRAINT

The Malcolm Pirnie equation in Attachment 3 of the WQMP is as follows:

$$TTHM = 7.21 \times TOC^{0.004} \times UVA^{0.534} \times (Cl2 - 7.6 \times NH3N)^{0.224} \times t^{0.255} \times (Br + 1)^{2.01} \times (pH - 2.6)^{0.719} \times T^{0.48}$$

where:

TTHM = total trihalomethane concentration (ug/L)
TOC = total organic carbon concentration after enhanced coagulation (mg/L)
UVA = ultraviolet absorbance at 254 nm after enhanced coagulation (1/cm)
Cl2 = available chlorine after enhanced coagulation (mg/L)
NH3N = ammonia concentration after enhanced coagulation (mg/L as Nitrogen)
t = chlorine contact time (hrs)
Br = raw water bromide concentration (mg/L)
pH = water pH after enhanced coagulation
T = raw water temperature (°C)

By employing several assumptions, the above equation reduces to a relationship that depends only on raw water temperature and three raw water constituents simulated by DSM2. Assumptions are per Attachment 3 of the WQMP unless noted otherwise:

1. Enhanced coagulation removes a fraction of TOC from raw water:
   a. TOC = 0.75 x raw water TOC if raw water TOC < 4 mg/L
   b. TOC = 0.65 x raw water TOC if raw water TOC ≥ 4 mg/L
2. DOC and raw water TOC are assumed to be equivalent (per B. Agee MWQI):
   a. DOC = raw water TOC
3. Enhanced coagulation removes a fraction of UVA from raw water (per data provided by S. Krasner MWDSC):
   a. UVA = 0.57 x raw water UVA if raw water TOC < 4 mg/L
   b. UVA = 0.46 x raw water UVA if raw water TOC ≥ 4 mg/L
4. Chlorine dose is sufficient to remove ammonia with free available chlorine in proportion to TOC:
   a. NH3N = 0
   b. Cl2 = TOC
5. t = 1 hr
6. pH = 7

When DOC < 4.0 mg/L:

$$TTHM = 7.21 \times (0.75 \times DOC)^{0.004} \times (0.57 \times UVA)^{0.534} \times (0.75 \times DOC)^{0.224} \times 1^{0.255} \times (Br + 1)^{2.01} \times (7 - 2.6)^{0.719} \times T^{0.48}$$

$$TTHM = 14.5 \times DOC^{0.228} \times UVA^{0.534} \times (Br + 1)^{2.01} \times T^{0.48}$$

When DOC ≥ 4.0 mg/L:

$$TTHM = 7.21 \times (0.65 \times DOC)^{0.004} \times (0.46 \times UVA)^{0.534} \times (0.65 \times DOC)^{0.224} \times 1^{0.255} \times (Br + 1)^{2.01} \times (7 - 2.6)^{0.719} \times T^{0.48}$$

$$TTHM = 12.5 \times DOC^{0.228} \times UVA^{0.534} \times (Br + 1)^{2.01} \times T^{0.48}$$

## ATTACHMENT 3
## DERIVATION OF TTHM CONSTRAINT AS A FUNCTION OF EC

The TTHM constraint was derived in Attachment 2 as follows:

$TTHM = C1 \times DOC^{0.228} \times UVA^{0.534} \times (Br + 1)^{2.01} \times T^{0.48}$

where:

TTHM = total trihalomethane concentration (ug/L)
C1 = 14.5 when DOC < 4.0 mg/L; C1 = 12.5 when DOC ≥ 4.0 mg/L
DOC = raw water dissolved organic carbon (mg/L) as simulated by DSM2
UVA = raw water ultraviolet absorbance at 254nm (1/cm) as simulated by DSM2
Br = raw water bromide concentration (mg/L) as simulated by DSM2
T = raw water temperature (°C)

DSM2 salinity simulations will be conducted in terms of EC and ANN results will report salinity results in terms of EC. Therefore, the above equation must be re-written in terms of EC instead of Br, requiring regression relationships between EC and Br at Old River at Rock Slough and other urban intakes. Development of necessary equations and related assumptions is documented in a May 29, 2001 memo from Bob Suits to Paul Hutton.

**Old River at Rock Slough**

The relationship between EC at Old River at Rock Slough and bromide at CCC PP #1 is as follows:

| | |
|---|---|
| $Br = -0.114 + 0.00096\ EC$ | for $EC \geq 129$ uS/cm |
| $Br = 0.01$ mg/L | for $EC < 129$ uS/cm |

where bromide is in mg/L and EC is in uS/cm. Substituting into the TTHM equation yields:

$TTHM = C1 \times DOC^{0.228} \times UVA^{0.534} \times (0.886 + 0.00096\ EC)^{2.01} \times T^{0.48}$ for $EC \geq 129$ uS/cm

$TTHM = 1.02 \times C1 \times DOC^{0.228} \times UVA^{0.534} \times T^{0.48}$ for $EC < 129$ uS/cm

**Other Urban Intakes**

The relationship between EC and Br at the other urban intakes (Banks Pumping Plant, Tracy Pumping Plant, and LVR intake) is as follows:

| | |
|---|---|
| $Br = -0.185 + 0.00098\ EC$ | for $EC \geq 199$ uS/cm |
| $Br = 0.01$ mg/L | for $EC < 199$ uS/cm |

where bromide is in mg/L and EC is in uS/cm. Substituting into the TTHM equation yields:

$TTHM = C1 \times DOC^{0.228} \times UVA^{0.534} \times (0.815 + 0.00098\ EC)^{2.01} \times T^{0.48}$ for $EC \geq 199$ uS/cm

$TTHM = 1.02 \times C1 \times DOC^{0.228} \times UVA^{0.534} \times T^{0.48}$ for $EC < 199$ uS/cm

## ATTACHMENT 4
## DERIVATION OF THE BROMATE CONSTRAINT

The Ozekin equation in Attachment 3 of the WQMP is as follows:

$BRM = 1.63\ E\text{-}06 \times TOC^{-1.26} \times pH^{5.82} \times O3DOSE^{1.57} \times Br^{0.73} \times O3TIME^{0.28} \times BRMCF$

where:

BRM = bromate concentration (ug/L)
TOC = total organic carbon concentration after enhanced coagulation (mg/L)
pH = water pH after enhanced coagulation
O3DOSE = ozone dose (mg/L)
Br = raw water bromide concentration (ug/L)
O3TIME = ozone contact time (minutes)
BRMCF = bromate correction factor

Again, by employing several assumptions, the above equation reduces to a relationship that depends only on two raw water constituents simulated by DSM2. Assumptions are per Attachment 3 of the WQMP unless noted otherwise:

1. Enhanced coagulation removes a fraction of TOC from raw water:
   a. TOC = 0.75 x raw water TOC if raw water TOC < 4 mg/L
   b. TOC = 0.65 x raw water TOC if raw water TOC ≥ 4 mg/L
2. DOC and raw water TOC are assumed to be equivalent (per B. Agee MWQI):
   a. DOC = raw water TOC
3. pH = 7
4. Ozone dose is in proportion to TOC:
   a. O3DOSE = 0.6 x TOC
5. Br (ug/L) = Br (mg/L) x 1000 (to provide units consistent with other constraints)
6. O3TIME = 12 min
7. BRMCF = 0.56

When DOC < 4.0 mg/L:

$BRM = 1.63\ E\text{-}06 \times (0.75 \times DOC)^{-1.26} \times 7^{5.82} \times (0.6 \times 0.75 \times DOC)^{1.57} \times (1000 \times Br)^{0.73} \times 12^{0.28} \times 0.56$

$BRM = 9.6 \times DOC^{0.31} \times Br^{0.73}$

When DOC ≥ 4.0 mg/L:

$BRM = 1.63\ E\text{-}06 \times (0.65 \times DOC)^{-1.26} \times 7^{5.82} \times (0.6 \times 0.65 \times DOC)^{1.57} \times (1000 \times Br)^{0.73} \times 12^{0.28} \times 0.56$

$BRM = 9.2 \times DOC^{0.31} \times Br^{0.73}$

## ATTACHMENT 5
## DERIVATION OF BROMATE CONSTRAINT AS A FUNCTION OF EC

The bromate constraint was derived in Attachment 4 as follows:

$BRM = C2 \times DOC^{0.31} \times Br^{0.73}$

where:

BRM = bromate concentration (ug/L)
C2 = 9.6 when DOC < 4.0 mg/L; C = 9.2 when DOC ≥ 4.0 mg/L
DOC = raw water dissolved organic carbon (mg/L) as simulated by DSM2
Br = raw water bromide concentration (mg/L) as simulated by DSM2

DSM2 salinity simulations will be conducted in terms of EC and ANN results will report salinity results in terms of EC. Therefore, the above equation must be re-written in terms of EC instead of Br, requiring regression relationships between EC and Br at Old River at Rock Slough and other urban intakes. Development of necessary equations and related assumptions is documented in a May 29, 2001 memo from Bob Suits to Paul Hutton.

**Old River at Rock Slough**

The relationship between EC at Old River at Rock Slough and bromide at CCC PP #1 is as follows:

$Br = -0.114 + 0.00096\ EC$ for EC ≥ 129 uS/cm
$Br = 0.01$ mg/L for EC < 129 uS/cm

where bromide is in mg/L and EC is in uS/cm. Substituting into the bromate equation yields:

$BRM = C2 \times DOC^{0.31} \times (-0.114 + 0.00096\ EC)^{0.73}$ for EC ≥ 129 uS/cm

$BRM = 0.035 \times C2 \times DOC^{0.31}$ for EC < 129 uS/cm

**Other Urban Intakes**

The relationship between EC and Br at the other urban intakes (Banks Pumping Plant, Tracy Pumping Plant, and LVR intake) is as follows:

$Br = -0.185 + 0.00098\ EC$ for EC ≥ 199 uS/cm
$Br = 0.01$ mg/L for EC < 199 uS/cm

where bromide is in mg/L and EC is in uS/cm. Substituting into the bromate equation yields:

$BRM = C2 \times DOC^{0.31} \times (-0.185 + 0.00098\ EC)^{0.73}$ for EC ≥ 199 uS/cm

$BRM = 0.035 \times C2 \times DOC^{0.31}$ for EC < 199 uS/cm

**ATTACHMENT 6**
**DERIVATION OF CHLORIDE CONSTRAINTS AS FUNCTIONS OF EC**

DSM2 salinity simulations will be conducted in terms of EC and ANN results will report salinity results in terms of EC. Therefore, chloride constraints are re-stated in terms of EC below for the key urban intakes utilizing the following conversion equations:

EC (uS/cm) @ Old River at Rock Slough = 89.6 + 3.73 Cl @ CCC PP #1

EC (uS/cm) = 161 + 3.66 Cl @ other urban intakes

The above conversion equations and related assumptions are developed and documented in a May 29, 2001 memo from Bob Suits to Paul Hutton.

**Old River at Rock Slough**

| EC (w/o Project) | EC (w/ Project) – EC (w/o Project) |
|---|---|

At CCC PP#1 when 150 mg/L chloride standard controls:

| | |
|---|---|
| 0.0 – 593 uS/cm | ≤ 37 uS/cm |
| > 593 uS/cm | ≤ 0 mg/L |

At CCC PP #1 when 150 mg/L chloride standard does not control:

| | |
|---|---|
| 0.0 – 929 uS/cm | ≤ 37 uS/cm |
| > 929 uS/cm | ≤ 0 mg/L |

**Other Urban Intakes**

| EC (w/o Project) | EC (w/ Project) – EC (w/o Project) |
|---|---|
| 0.0 – 984 uS/cm | ≤ 37 uS/cm |
| > 984 uS/cm | ≤ 0 mg/L |